FINITE ELEMENT ANALYSIS OF HUMAN LUMBAR VERTEBRAE IN PEDICLE SCREW FIXATION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Industrial Design

By

Rishikant Sahani
(Roll: 213ID1369)

Department of Industrial Design
National Institute of Technology
Rourkela-769008, Orissa, India
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CERTIFICATE

This is to certify that the work in the thesis entitled, "**Finite element analysis of human lumbar vertebrae in pedicle screw fixation"** submitted by **Mr. Rishikant Sahani** in partial fulfillment of the requirements for the award of **Master of Technology Degree** in the Department of Industrial Design, National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the work reported in this thesis is original and has not been submitted to any other Institution or University for the award of any degree or diploma.

He bears a good moral character to the best of my knowledge and belief.

Place: NIT Rourkela
Date:

Prof. Mohammed Rajik Khan
Asst. Professor
Department of Industrial Design
National Institute of Technology, Rourkela

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For each and every new activity in the world, the human being needs to learn or observe from somewhere else. The capacity of learning is the gift of GOD. To increase the capacity of learning and gaining the knowledge is the gift of GURU or Mentor. That is why we chanted in Sanskrit "*Guru Brahma Guru Vishnu Guru Devo Maheswara, Guru Sakshat Param Brahma Tashmey Shree Guruve Namoh*". That means the Guru or Mentor is the path to your destination.

The author first expresses his heartiest gratitude to his guide and supervisor *Prof. Mohammed Rajik Khan, Assistant* Professor of Industrial Design Department for his valuable and enthusiastic guidance, help and encouragement during the course of the present research work. The successful and timely completion of the research work is due to his constant inspiration and extraordinary vision. The author fails to express his appreciation to him.

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Rishikant Sahani

ABSTRACT

In totality of 100%, near about 85% of adult's falls back pain, which directly related to their daily assignments and activities and 25% of people, reported lower back pain, which is associated with the vertebral compression. Spinal de-generation is also a medical situation which directly affecting men and women of different age groups. Spine injury is mostly found on vertebrae L1– L5 and corresponding intervertebral disk and in this analysis, the purposes of the present research are conclude the appropriate dimensions of pedicle screw (diameter and length) for its fixation in L2–L3-L4 vertebral region. In this analysis pedicle screw of Titanium with different diameters 5, 5.5, 6.0, 6.5 mm. and length 45, 50 mm have been considered. Further to this Finite element analysis (FEA) with boundary condition, i.e. fixed bottom surface of the L4 vertebrae and loads were applied on top surface of L2 vertebrae. The different loading condition has been considered for various body weights. Results were analyzed to provide appropriate pedicle screw size.

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ABBREVIATIONS & SYMBOLS

1.	FEA	Finite Element Analysis
2.	FEM	Finite element method
3.	3D	Three dimension
4.	BMD	Bone mineral density
5.	L2	Lumbar 2
6.	L4	Lumbar 4

CHAPTER 1

1. INTRODUCTION

A pedicle screw plays an essential characters within the treatment of spinal degeneration problem by providing strength, support and affiliation between broken bones. Although successfully pedicle screw is responsible for long term stability of human lumbar spine segments in over 90 % cases, screw loosing, fracture and pullout still contribute to important failure rate[1].A reduction in biomechanical properties is responsible for surgical failure, which is developed is due to excessive native loading on the vertebral body. To ensure long term stability, material properties and pedicle screw size are very important. According to many studies of the bone- screw interface play an important character in pedicle screw fixation. The fixation stability is affected by different parameters like diameter of screw, length of the screw, material properties of screw, thread design of a screw, implant location, implant path, Implant skill and quality of the bone [1]. Proper threading and material choice is the most effective way of safely increasing the withdrawal strength of the pedicle screw. The total information about this parameter affects the victory of spine surgery is important in order to make effective medical decisions about the diameter and length of the screws to be inserted.

The input parameters of pedicle screws that have an effect on addiction strength are measured mainly by biomechanical experiments. Many earlier investigators have demonstrated that increasing the diameter of pedicle screws improves the strength of screw fixation and reduces the stress on the vertebral sector. However, as a result of all biomechanical studies have solely examined screws of various diameters not take into account length the results of implant diameter and length on a distinct region of the vertebral bone is remains unclear. The optimal range of pedicle screw size like the length and diameter is very difficult to define. It is necessary to understand the role of pedicle screw size in regions with different quality bones and different loads. A variety of pedicle screw size and different biomechanical properties of the screw is very helpful for spinal surgeons.

1.1. Anatomy and biomechanics

The bony spinal anatomy is a complex structure designed to support the weight of the higher body, allow physiologic motion, and care for the spinal cord .The spine is made up of vertebral bodies, which are composed of a tough external shell of cortical bone and a spongy inner

structure of trabecular bone. There are a total of 33 vertebras in the human body: seven cervical
(C1-C7), twelve thoracic (T1-T12), five lumbar (L1-L5), five fused sacral and three to four fused coccygeal vertebrae as shown in Fig. 1.1

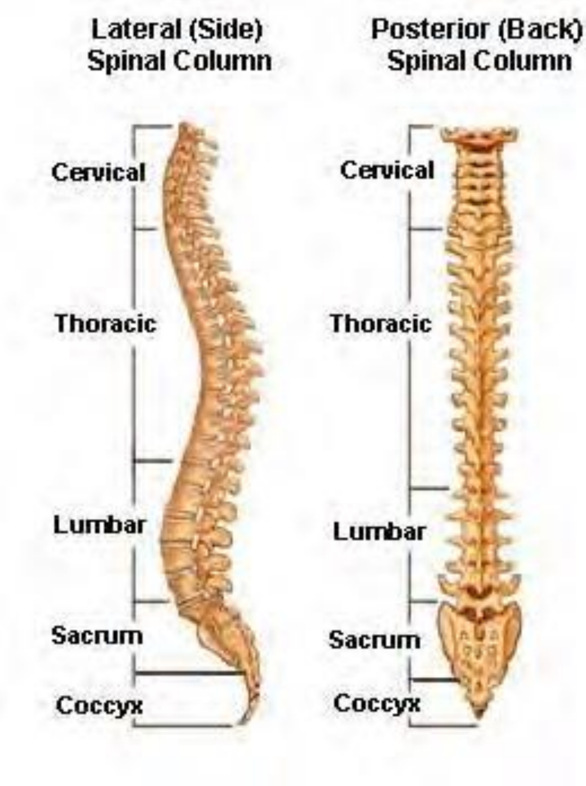


Fig. 1.1 Human spine in lateral and posterior view [2]

1.1.1 Vertebrae, posterior elements

The vertebra (fig.1.2) can be divided into two parts – the anterior body and the posterior elements. The anterior body takes most of the compressive loading of the spine. It is comprised of a porous trabecular bone surrounded by a cortical shell. The posterior elements, which consist of the pedicles, lamina, transverse processes and spinous process, forms a protective arch over the cord that resides posterior of the vertebral body.

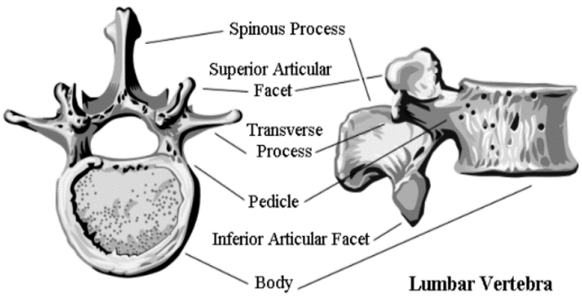


Fig.1.2 Anatomy of lumbar vertebrae [3]

1.1.2 Intervertebral disc

The intervertebral discs (fig.1.3) are designed for weight bearing and motion. They consist of the cartilaginous endplates, outer annulus fibrosus and inner nucleus pulposus. The endplates are the attachment site to the vertebral bodies and allow for nutrition transfer into the disc. The annulus fibrosus consist of rings of crisscrossing oblique fibers that limit rotation and contain the nucleus. The nucleus pulposus is a semifluid gel that will easily deforms, but is incompressible. There is a high water content within the disc and the combination of these structures allow the disc to handle large compressive loads.

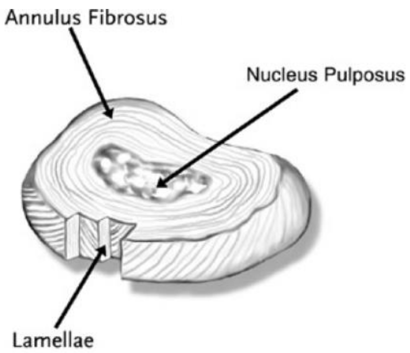


Fig.1.3 Intervertebral disc showing nucleus pulposus and annulus fibrosus [3]

1.1.3 Functional spinal unit

A functional spinal unit (FSU) consists of two vertebrae, a disc, two facet joints and any other structures that span between these two vertebrae. This is considered the basic functional unit of the spine, and is studied to evaluate the effects disease, degeneration, implants or other procedures have on spinal biomechanics. The disc allows motion in six degrees of freedom, yet motion is limited by the fibers in the disc as well as the ligaments, facet joints and other structures of the spine.

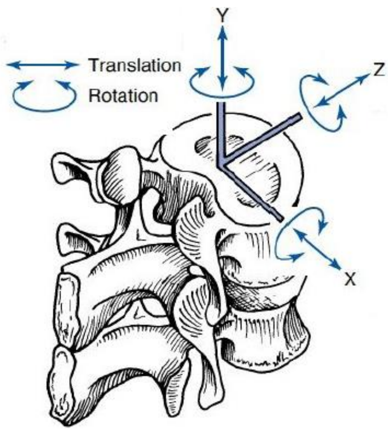


Fig.1.4 The functional spinal unit has six degrees of freedom [4]

1.2. Project background

The number of elderly population is increasing gradually in the world. Age-related spinal degeneration is becoming a major problem for the older generation and causes tremendous pain [5] .This problem can be reduced by the help of pedicle screw, the use of pedicle screws in spinal surgery is broad and encompasses the treatment of deformity, trauma, cancer and degenerative disorders, including degenerative lumbar spine disease.

A common form of treatment is fusion and decompression of the lumbar spine with use of pedicle screws as the primary mode of stabilization (Fig.1.5). These screws are inserted from posterior to anterior (i.e. from the back to the front of the vertebral body). Screws in adjacent bodies are rigidly connected via rods to one another to achieve fusion or stabilization of adjacent vertebra (Fig.1.5).

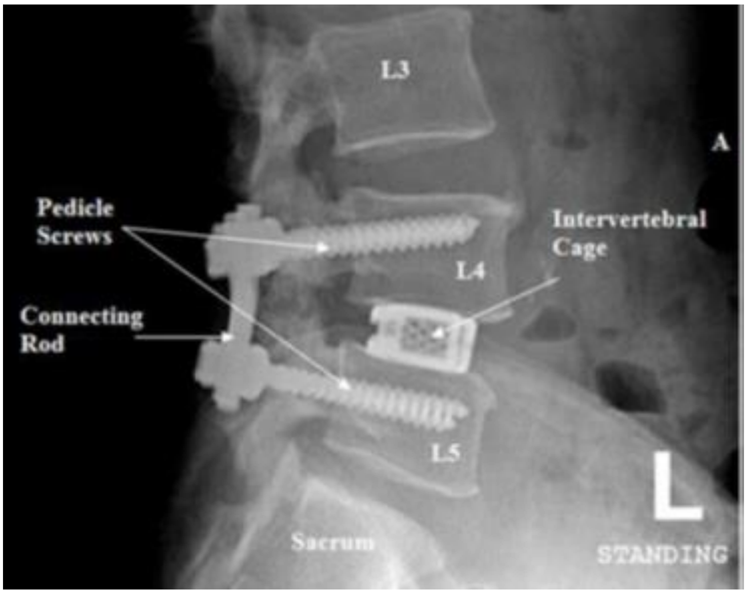


Fig.1.5. Pedicle screw and cage inserted between lumbar vertebrae L4 to L5 [6]

Lumbar spine fusion is a surgical way in which two or more vertebrae in the spine are combined together so that motion no longer occurs between them and provide stability across degenerative or unstable motion segments. This lateral x-ray of the lumbar spine shows pedicle screw instrumentation of the L4 vertebra and L5 vertebra. An intervertebral cage is also used to re-establish lost vertebral disk height and to promote bony fusion [6]

1.3. Problem statement

The mechanical stress variations in 3D modal of lumbar vertebrae L2-L4 vertebral with various pedicle screws were evaluated. Generation of stresses on the adjacent vertebral segments due to various load to be also examined using Finite Element Method.

1.4. Objectives

The aims of the present research are as follows:

- To determine the appropriate dimensions of pedicle screw (diameter and length) for its fixation in L2 to L4 vertebral region at different load conditions using FEA.
- To perform FE analysis in cortical, cancellous and pedicle bones while insertion of pedicle screw.

1.5. Methodology

- Generate a 3 D modal of lumbar spine from L2 to L4 with intervertebral disc.
- Division of 3D modal of lumbar spine in cortical, cancellous, and pedicle bone.
- Pedicle screws modelled and placed in lumbar vertebrae.
- 3D implant modal of lumbar spine imported and mesh generated at different regions.
- Stress generated in lumbar vertebrae due to various size of pedicle screw were assessed.
- Statistical analysis have been performed on the basis of stress value.

1.6. Organization of the work

The thesis defining the current research effort is distributed into six stages. The theme of the topic its relative significance and the associated materials containing the objectives of the work are offered in Chapter 1. The reviews on some different Streams of literature on changed issues of the topic such as pedicle screw fixation, Trajectory, insertion techniques and screw characteristics, Bone mineral density, Morphometric and Modeling of lumbar spine etc. are presented in Chapter 2. In Chapter 3, generation of lumbar vertebrae and design of different sizes of pedicle screw had done, Chapter 4 all simulations are carried out in ANSYS. In Chapter 5, result and discussion on simulation output and further statistical analysis, as a final point, Chapter 6 presents the conclusion and future scope of the investigation work.

CHAPTER 2

2. Literature Review

2.1. Overview

In the field of spine surgery effect of pedicle screw fixation in human lumbar spine works had previously been done. Major landmark works are tabularised in table 2.1. Further survey on Trajectory, insertion techniques and screw characteristics, Bone mineral density, Morphometric and Modeling of lumbar spine these are also play a very crucial role in spine surgery.

2.2. Major works done so far on pedicle screw fixation in lumbar spine

Table 2.1: Key works done in the field of pedicle screw fixation

S. No.	**Title**	**Author**	**Source**	**Software and tools**	**Remark**
1	Loading of pedi cle screws within the verte brae	Scott A. Yerby	Journal of Biomec hanics (1997)	Aluminium Mold, Corpectomy model.	Measured the bending moments of pedicle screws within the body part of vertebrae and to use these measurements to make an empirical mathematical equation concerning

					screw dimension and bone load to screw bending moments.
2	Biomechanical investigation of pedicle screw–vertebrae complex: a finite element approach using bonded and contact interface conditions	S.-I. Chen	Medical Engineering & Physics (2003)	CT, Pro/E, ANSYS5.5	Investigated the effect of different interface condition (Contact and Bonded) in the pedicle screw and vertebrae under several loading condition.
3	Investigation of fixation screw pullout strength on human spine	Q.H. Zhang	Journal of Biomechanics (2004)	ANSYS 5.7, Pro/E	Analysed the Behavior of the bone and pedicel screw throughout the method of screw pull-out, and therefore the special effects of the screw parameters on the retreat strength of fixation screw on the body part of vertebral column.

4	Finite-Element Analysis for Lumbar Inter body Fusion Under Axial Loading	K. K Lee	IEEE Transactions On Biomedical Engineering(2004)	Faro Arm, Bronze Series, ANSYS 6.0	Investigated axial toughness of the lumbar inter body union, compressive stress, in addition expanded in the endplate due to fluctuations in the insertion location with/without combination bone using an anatomically correct and authorized L2-L3 finite-element model.
5	Failure analysis of broken pedicle screws on spinal instrumentation	Chen-Sheng Chen	Medical Engineering & Physics (2005)	CAMSCAN 4D, SEM	Focus on retrieval investigation of stresses to study features that produced pedicle screw breakage information.

6	Optimum design of an inter body implant for lumbar spine fixation	Andre´s Tovar	Advances in Engineering Software (2005)	GENESIS, PMMA	Performed multi-objective optimization process, topology optimization monitored by shape optimization and further design maximizes the capacity distributed for the bone implant material and conserves von Mises stress levels in the implant beneath the stress limit.
7	Biomechanical study of lumbar spine with dynamic stabilization device using finite element method	Dong Suk Shina	Computer-Aided Design (2007)	AMIRA, 3D reverse engineering, ANSYS	Investigated the stiffness of an active balance device in Spinal sections (L2–L5) and the impact on the movement of neighbouring intervertebral sections using.
	Comparison of the effects of bilateral posterior dynamic and	Antonius Rohlmann	Eur Spine J (2007)	ABAQUS, version 6.5, MSC/PATRAN	Comparative investigation of a geometrically easy mono segmental an active fixation

8	rigid fixation devices on the loads in the lumbar spine: a finite element analysis				scheme and a rigid fixator for their special properties on intersegmental turning, intradiscal pressure, facet joint forces and implantation forces. An additional work that analysis the special effects of implant rigidity on intersegmental spin using a 3D nonlinear finite element model.
9	Study of stress distribution in pedicle screws along a continuum of diameters: a three-dimensional finite element analysis	Wei Qi MD	Orthopaedic Surgery (2011),	Mimics, 11.1, Pro/E, ANSYS, CT	Optimized the diameter of pedicle screw for assignment in human lumbar vertebrae (L1) which are biomechanically comfortable by distribution of maximum stresses in lumbar vertebrae as well as screws by finite element analysis.

10	A Finite Element study of Spinal Implant(pedicle screw) Design for Lumbar(L3–L5) Vertebra	Biswas, J.	Indian Journal of Biomechanics (2012)	MIMICS 10.01, ANSYS 12, CT	Comparative analysis of stresses which developed in lumbar vertebrae (L3-L5) under the condition of various load for the design of lumbar vertebrae (L3-L5) implant using finite element method.

2.3. Trajectory, insertion techniques and screw characteristics

Van de Kelft, et al (7), proposed a method of pedicle screw settlement in common spine surgery by O-arm 3-dimensional (3D) imaging, an intraoperative computed tomographic (CT) scan, shared with a present navigation arrangement. This technique increase the accuracy of pedicle screw settlement as example in 100% totality 97.5%, the screws are appropriately placed and only 2.5% of the screws inappropriate.

Silbermann, J., et al (8), proposed a Comparative investigation of two technique first is O-arm based-S7-navigation and second is free-hand technique for accuracy of implant settlement in lumbar and sacral spine using CT scans. Free-hand technique is safe and accurate when it is in the hands of an experienced surgeon. The precision of implant settlement with O-arm technique is best because the learning arc of O-arm is great when equated to the free-hand method which has an abrupt learning curve and needs a lot of exercise to become a great accurateness proportion.

Allam, Y., et al, (9), proposed a Comparative investigation of two technique first is 3D-based navigation technique and second is free hand technique for the estimate accurateness of pedicle screw settlement in thoracic spine. This system shows that the 3D-based navigation technique provides high accuracy of pedicle screw placement and thus safe for the patients undergoing thoracic spine stabilization. It allows immediate detection of screw misplacement and accordingly no reoperation for malposition. In comparison to lumbar spine, placement of transpedicular screws in the thoracic spine using 3D-based navigation technique is superior to the free hand technique.

Sugimoto, Y., et al, (10), proposed a 3D Fluoroscopy Navigation system to measure the pedicle isthmic width and the authorization angle for pedicle fasten placement in upper lumbar vertebrae. Pedicle screw misplacement in upper lumbar is minimum when using 3D Fluoroscopy Navigation system because upper lumbar vertebrae keep more tapered width and angles pedicles.

Bijukachhe, B., et al (11), proposed a free hand technique known as funnel technique to measurement the precision of pedicle screw settlement in Dorsal / Lumbar/ Sacral spine. This technique is more securely but very costly as well as taken more time

2.4. Bone Mineral Density

Salo, Sami, et al, (12), investigated higher lumbar bone mineral density (BMD) is direct relation with the lumbar disc degeneration (LDD) and controversial relation between femoral neck BMD and LDD and also Analyse the association between LDD and BMD of the human vertebral column and femoral neck.

Douchi, T., et al, (13), associated the stability of human vertebral column bone mineral density in one areas to other areas varies with stage. Consider females aged 20–49 years and choice the arms, vertebral column (l2 -l4), pelvis, legs, and whole body for measure the BMD by dual-energy X-ray absorptiometry (DEXA).Below 40years women no difference between area and total body bone mineral density but above 50 years area and total body BMD progressively reduced with stage.

Sabo, M. T., et al, (14), investigated the bone mineral density along path of the screw before and after screw placement by high-resolution computed tomography scans, for this measurement consider cadaveric human sacra as a model with titanium screws both hollow and solid.

2.5. Morphometric and Modeling of lumbar spine

Singel, T. C et al, (15), proposed a work for measure the dimension of lumbar pedicle in Saurashtra region (western India) with the help of Sliding Vernier Calliper for this study consider adult lumbar vertebrae. In vertebral column pedicle size increase from L1- L5 when consider width which used for support in loads communication and when consider height of lumbar pedicle size drops from L3- L5 levels.

Gocmen M., et al, (16), proposed a work for measuring the external shape and volumetric calculation of lumbar frames and discs using stereology method. To donate a safe anterior methodology during operation. The average measurements of men vertebrae are more than those of women, but greatest of them do not fluctuate statistically. Only three dimensions, the mean variance between anterior and fundamental heights of L3, L4 and L5 showed statistically important modification, representing smaller fundamental height in both men and women. This provide estimation of relating implant dimensions and measure in decompression procedures for neurosurgeon.

Zhou, S. H., et al, (17), proposed a work for Measurements of several features of vertebral sizes and geometry from digitised CT image containing lumbar column height. This anthropometric features of the lumbar column reviewing by the help of the Picture Archiving Communication System (PACS) attached with its interior evaluating equipment. The dimensions of the lumbar column endplate improved from the third to the fifth lumbar column. Frontal vertebral height unchanged from the third to the fifth vertebra, but the posterior vertebral height decreased. This is significant evidence for the technical development of spinal operation and for the strategy of back bone implants.

Ben-Hatira, F., et al (18), Designated the mechanically relation between pathologies of the human back bone from L1 – L5 and the spinal structure by providing spinal cord deformation in various loading condition. Consider a nonlinear three-dimensional finite element method is used as a numerical tool to perform all the calculations. In this especially focus on Spinal cord stress which is correlated with pressure of the vertebral element. Analysis of stress (maximum equivalent and shear) play a very important role when compressive load combined with a flexion and a lateral bending.

Li, H., et al, (19) investigated the biomechanical features of lumbar spine from L1-L2 with intervertebral disc in the compression loading condition using the finite element method based on medical image.

Divya, V., et al (20) investigated the morphometry of lumbar vertebrae from L1 –L5 collected from patients CT data and converting in 3d model using MIMICS software for the stress-strain relationship in these vertebrae under same axial compression loaded and unloaded condition.

Zulkifli, A., et al (21) Investigated the generation of maximum stress on the vertebra due to the Hyperextension condition and calculate the probability of failure for the current model.in this study is that the pedicle is the most critical region that affects the vertebrae when the facet joints are subjected to hyperextension loading.

Karabekir, H., et al (22) investigated the standard dimension of vertebral column such as pedicle, intervertebral space, vertebral body, foramen, height and volume for safe surgical involvement by a posterior fixation methodology to offer support the unhealthy human lumbar body. This technique provide morphometry of lumbar vertebrae which is simplify the application of pedicle screws.

2.6. Summary

Maximum researchers have been performed vitro and vivo analysis of lumbar vertebrae for investigate the variations of stress, due to bone mineral density, Trajectory, insertion techniques, dimensions of pedicle screw by finite element method. Optimization of pedicle screw also have been done for single vertebrae like L2 with various diameter with constant length. Basically the disadvantages of one unit will be enclosed by the further and vice versa.

CHAPTER 3

3. Modeling Of Lumbar Vertebrae With Pedicle Screw

3.1. Overview

In this chapter deals with generation of 3D lumbar spine L2-L4 and further design the pedicle screw with various dimensions. Material properties of bones have a varying nature mainly depends on the age, weight, healthy and unhealthy persons and also differ from one region to other regions. Consider material properties of bone of healthy man.

3.2. Generating 3d model of lumbar vertebrae

Three dimensional human spine taken from GRABCAD which are online available for education purpose freely. We consider human lumbar vertebrae L2 – L4 with intervertebral disc further imported in SOLIDWORKS12 for categorization in five parts of lumbar vertebrae and two parts of intervertebral disc as shown in fig.3.1

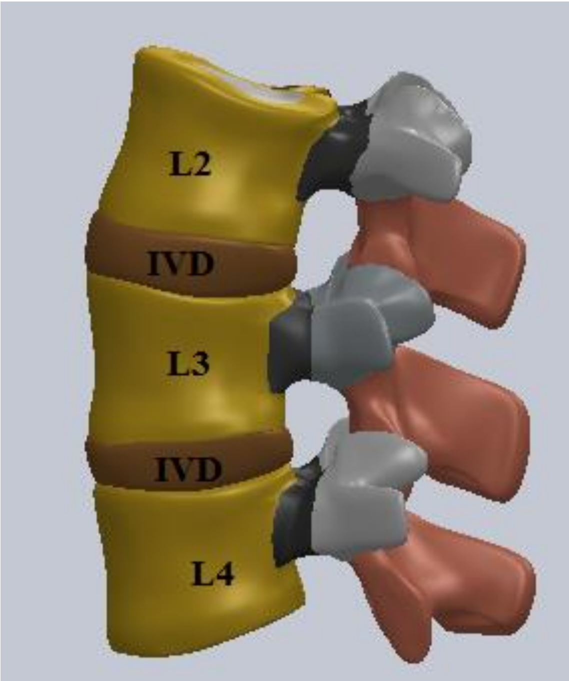


Fig.3.1 Human Lumbar vertebrae L2-L4 with Intervertebral Disc

Lumbar vertebrae parts are cortical bone, cancellous bone, pedicle, transverse process and spinous process which are following there.

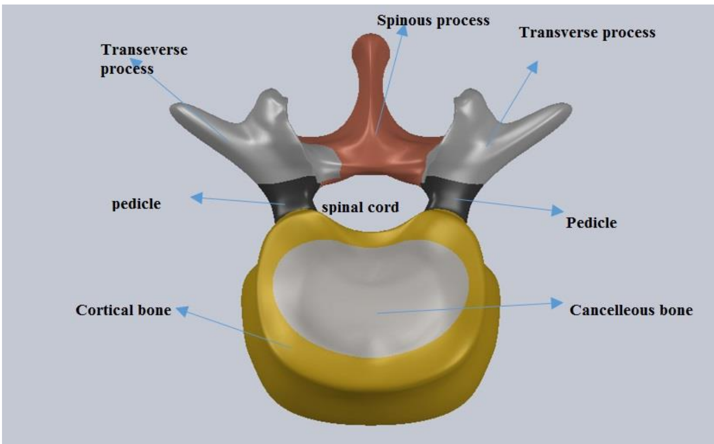


Fig.3.2 Different regions in lumbar vertebrae

Intervertebral disc is divided in two parts first one annulus fibrosus and second nucleus pulposus.

3.3. Design of pedicle screw and connecting rod

Much has to be thought-about once determinative the correct pedicle screw size to be used for spinal fusion in spinal degeneration patient. Aggregate the diameter and length of the screw has the potential to supply larger disengagement forces, however they additionally increase the danger of fracturing the encircling, brittle bone [23].Developing a screw with accurate thread style is crucial in achieving best results among the shape because the most popular size, shape, and pitch can vary supported specific anatomy. As an example, in ancient mechanical style, a screw with a deep thread and enormous pitch is most popular in softer mediums to prevent husking, whereas a smaller thread size and pitch are ideal wherever material strength might not be a priority, however size could also be a limiting issue. We have a tendency to consider following thread design for spinal degeneration patients.

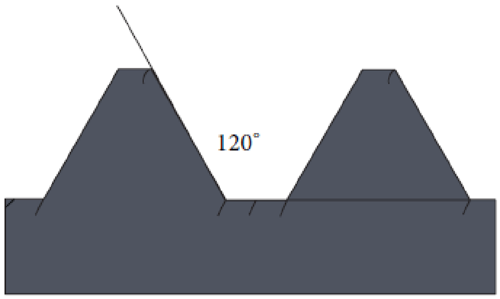
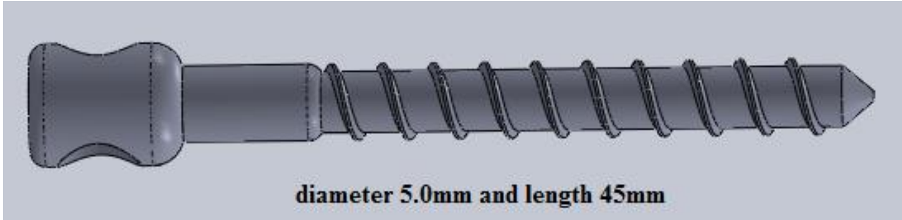
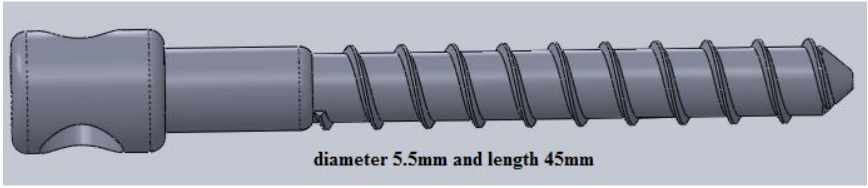


Fig.3.3 Pedicle screw thread design angles [23]

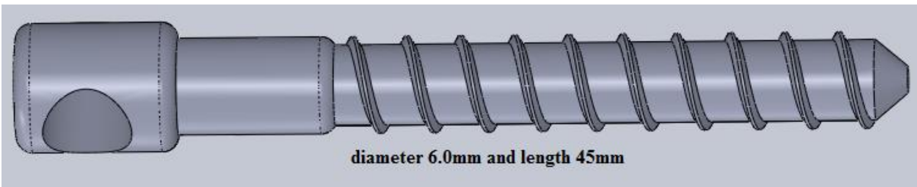
The pedicle screw was generated using SOLIDWORKS12 software. A 3-D solid screw model was established that was visually same to an existent screw. Screw diameter (D) and length was a changeable variable. Diameter ranged from 5.0 mm to 6.5 mm and Screw length 45 mm and 50 mm. So design matrix suggest to make eight pedicle screw. In following figures 3.4 & fig. 3.5 shows pedicle screw of different size.



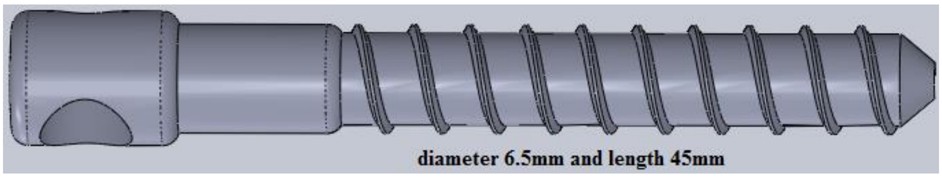
(a)Pedicle screw with Diameter 5.0mm and length 45mm



(b) Pedicle screw with Diameter 5.5mm and length 45mm

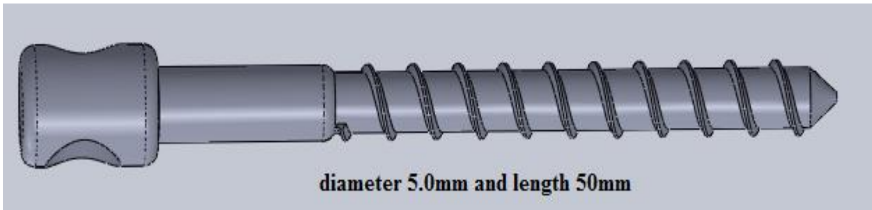


(c) Pedicle screw with Diameter 6.0mm and length 45mm

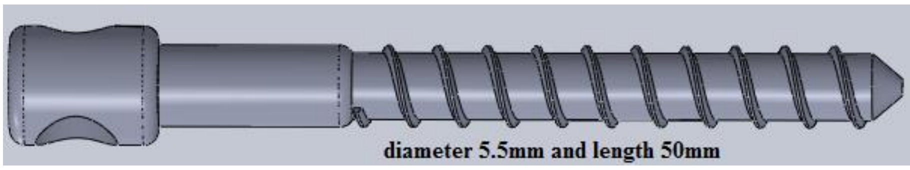


(d) Pedicle screw with Diameter 6.5mm and length 45mm

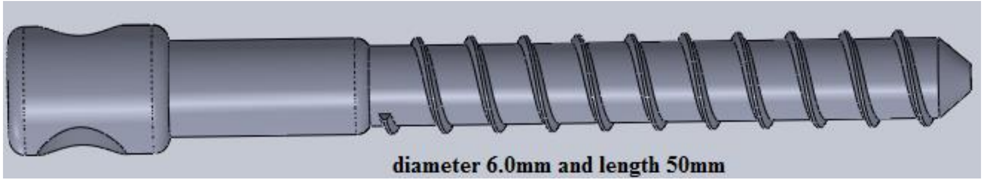
Fig.3.4 pedicle screw length 45mm (a) dia.5.0mm (b) dia.5.5mm, (c) 6.0mm (d) 6.5mm



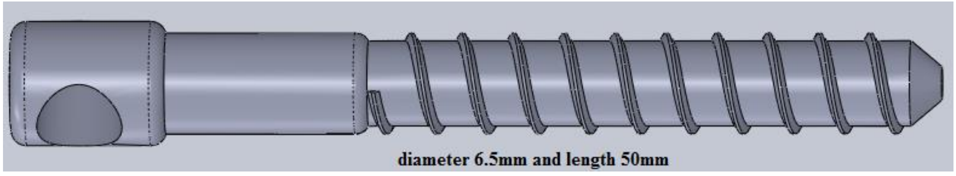
(a) Pedicle screw with Diameter 5.0mm and length 50mm



(b) Pedicle screw with Diameter 5.5mm and length 50mm



(c) Pedicle screw with Diameter 6.0mm and length 50mm



(d) Pedicle screw with Diameter 6.5mm and length 50mm

Fig.3.5 pedicle screw length 50mm (a) dia.5.0mm (b) dia.5.5mm, (c) 6.0mm (d) 6.5mm

Connecting rod was also modelled in solid works consider diameter 5.5mm with titanium material shows in figure. 3.6.

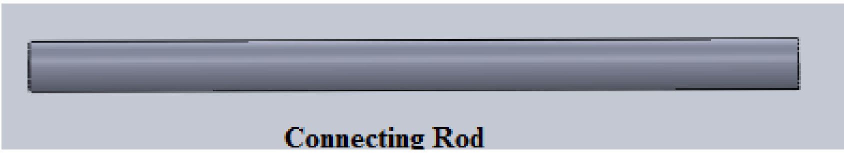


Fig.3.6 Connecting rod

Pedicle screw of different size, connecting rod, and 3D modal of lumbar spine L2 – L4 are assembled in SOLIDWORKS12 using different tools and prepare eight modal of lumbar spine L2 –L4 with pedicle screw implant for further process which shown in figure (3.7)

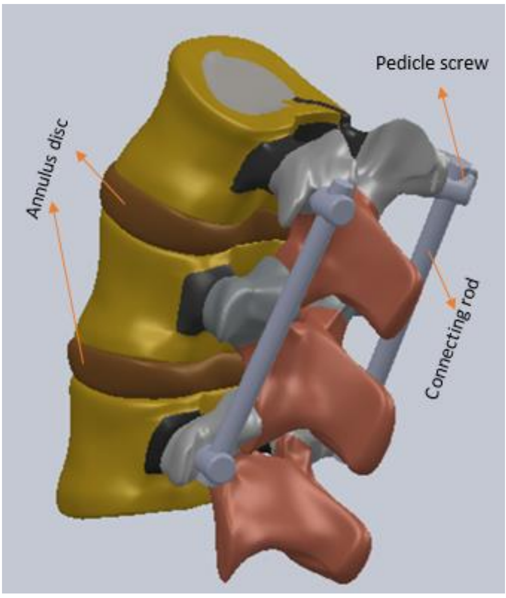


Fig.3.7 Lumbar vertebrae L2 –L4 with implant

3.4. Material properties

Mechanical properties of human spine is depends on bone mineral density. Which have different nature in one regions to other regions differs with age [13] all the materials in the model were considered elastic and isotropic which require two parameters to describe their properties: E (elastic modulus) and ν (Poisson's ratio).We have consider material properties of bone and intervertebral disc from healthy man which listed in table 3.1.

In addition to sterilisation the anatomical options of the pedicle screw, the screw material might additionally have an effect on however well it's ready to reach correct anchorage in caliber bone. As an example, several pedicle screws are created out of stainless steel as a result of its biocompatibility and high strength but, titanium has been thought of to possess superior mechanical and biological properties over stainless steel [23].We have taken into account titanium material for pedicle screw and connecting rod.

Table 3.1: Mechanical properties of the materials used in the 3-D finite element models

S. No	Component name	Material properties		
		Young's Modulus (Mpa)	**Poisson's Ratios**	**References**
1	Cortical bone	12000	0.3	Kurutz, M., & Oroszváry, L (24) Deoghare, A. (25)
2	Cancellous bone	100	0.2	Deoghare, A. (25)
3	Posterior bone	3000	0.3	Deoghare, A. (25), Schmidt, H.,(26)
4	Annulus Disc	4.2	0.45	Deoghare, A. (25)
5	Nucleus Disc	1	0.499	Deoghare, A. (25)
6	Pedicle Screw Titanium	110000	0.3	Rohlmann, A.,(27)
7	Connecting rod titanium	110000	0.3	Rohlmann, A.,(27)

3.5. Summary

Various dimensions of pedicle screw have been prepared and inserted in lumbar vertebrae. Material properties have been taken from previous researchers.

CHAPTER 4

4. Finite Element Analysis of Lumbar Vertebrae With Pedicle screw

4.1. Overview

The finite element method (FEM) is a numerical technique for representing and simulating physical systems. The geometry is replaced with a set of elements, consisting of nodes with a finite number of degrees of freedom. This method inspecting sensations that cannot be elucidated by experimental methods, like peak of the biomechanical procedures, for example fractured bone between vertebrae, osteoporosis and spinal degeneration courses. Moreover, this procedures have the probable to decrease costs and to save period during the improvement of novel active technique [28]. Therefore, there is a requirement to acquire more and more faithful and accurate mathematical models for the very difficult arrangement, the human spine. In this part the FE modeling features of the most visited lumbar vertebrae part.

4.2. FE Modeling of 3D lumbar vertebrae

The 3D lumbar vertebrae and pedicle screw were grouped as a basic screw-bone 3-D solid model by using the SolidWorks assemblage function and this model was imported into ANSYS for **observation** and analysis.

It is familiar that the implant 3D model of lumbar spine is a complex body, that is, it contains of distinct infrastructures, with several elastic and geometry properties. The weight distribution and transmission among the infrastructures depend on several elements. The relationship between contacts faces of entirely models were provided as “bonded”. [29]

4.2.1 Meshing

Three-dimensional meshes generated at different part of lumbar spine, pedicle screw and connecting rod. Tetrahedral [25] and hexahedral element generally used for simulation. Mesh details is listed in table 4.1 and fig 4.1

The element size have been taken 3 mm on usual, and the total number of elements and nodes is varied for different screw dimension modal shown in table 4.2.

Table 4.1 Nature of meshing element in different regions

S.No	Components name	Element types	Reference
1	Cortical bone	Tetrahedral	Deoghare, A. (25), Chen, S. I.,(29)
2	Cancellous bone	Tetrahedral	Deoghare, A. (25),Chen, S. I.,(29)
3	Pedicle	Tetrahedral	Deoghare, A. (25),
4	Spinous	Tetrahedral	
5	Transverse	Automatic	
6	Annulus Disc	Tetrahedral	
7	Nucleus Disc	Tetrahedral	
8	Pedicle Screw Titanium	Tetrahedral	Deoghare, A. (25),Chen, S. I.,(29)
9	Connecting rod titanium	Automatic	

Table 4.2. Total Number of nodes and elements in different modals

S.No	3D modal of lumbar spine L2-L4 with implants Conditions	Nodes	Elements
1	Diameter 5.0mm and length 45mm	156873	90557
2	Diameter 5.5mm and length 45mm	153263	88319
3	Diameter 6.0mm and length 45mm	158967	91668
4	Diameter 6.5mm and length 45mm	153887	88555
5	Diameter 5.0mm and length 50mm	161714	93744
6	Diameter 5.5mm and length 50mm	155804	89584
7	Diameter 6.0mm and length 50mm	152480	87553
8	Diameter 6.5mm and length 50mm	156222	89586

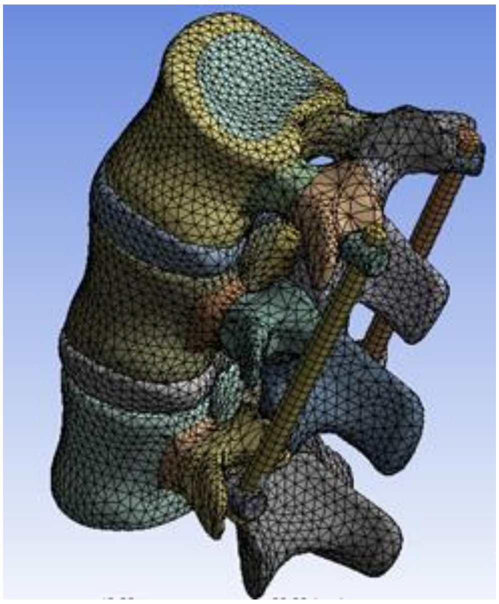
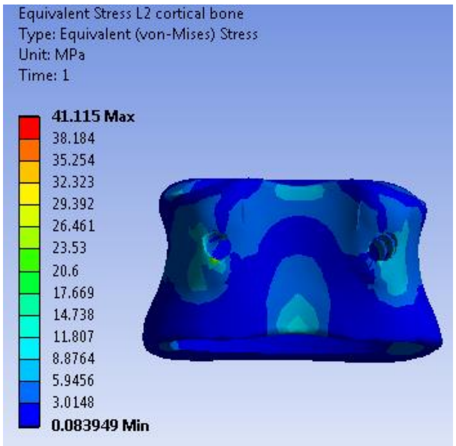


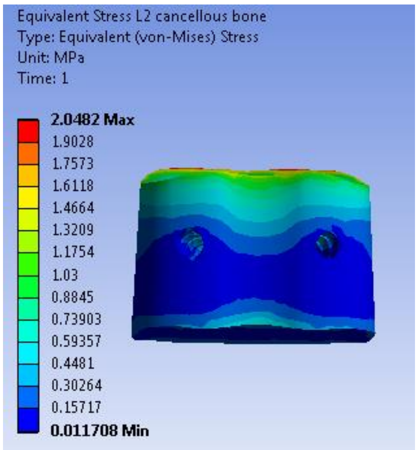
Fig 4.1 3D implant modal of lumbar spine with various mesh

Although in vitro loads of the vertebral addiction system have been recorded [30], and vitro analysis for design of pedicle screw using the different load (420, 490.5 & 588.6 Newton) [5] has been taken for different body weight (70 kg, 90 kg and120 kg respectively) we have considered magnitude of the forces 588.6 and 490.5 newton load for analysis. The boundary condition were, fixed at lower surface of the L4 vertebra and load were applied on the top surface of L2 vertebrae.

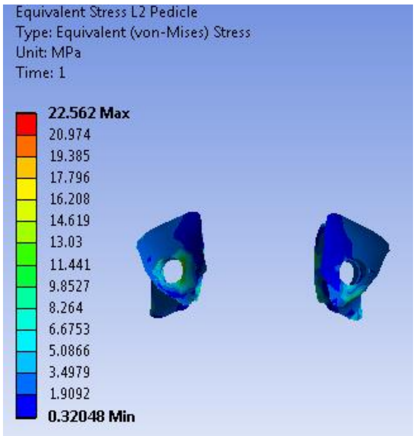
4.2.2 Stress and deformation analysis

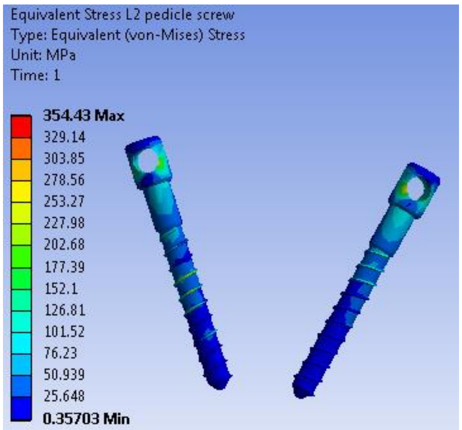
Maximum equivalent stress generated in 3D modal of lumbar spine with implants which is shown in below figure has more important.





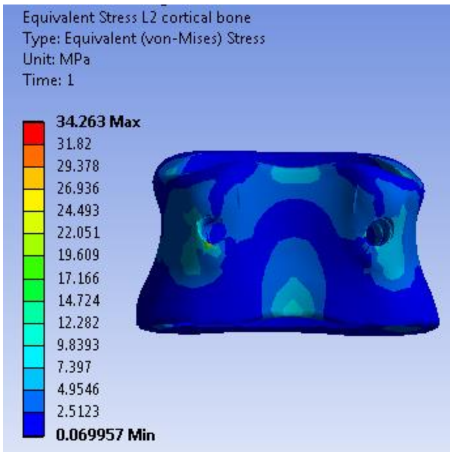
(a) **(b)**



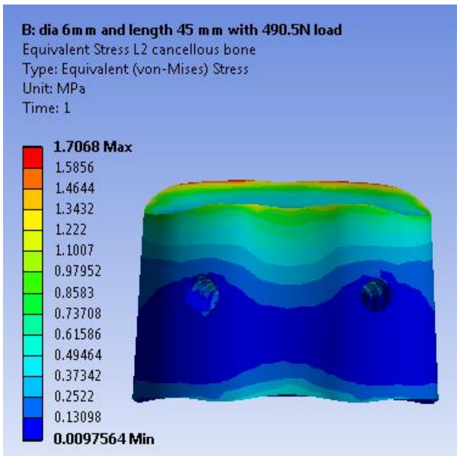


(c) **(d)**

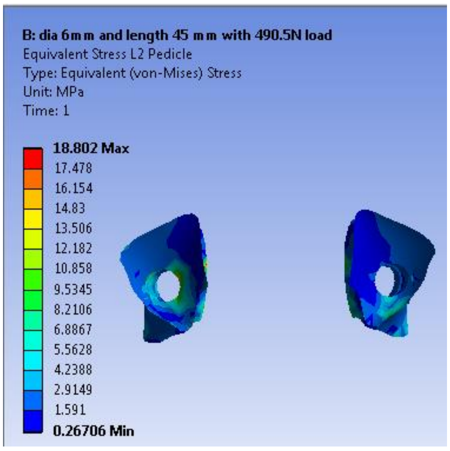
Fig.4.2 Maximum equivalent stress value in screw dia. 6.0mm and length 45 mm under the load value 588.6 N at (a) cortical bone (b) cancellous bone (c) pedicle (d) pedicle screw



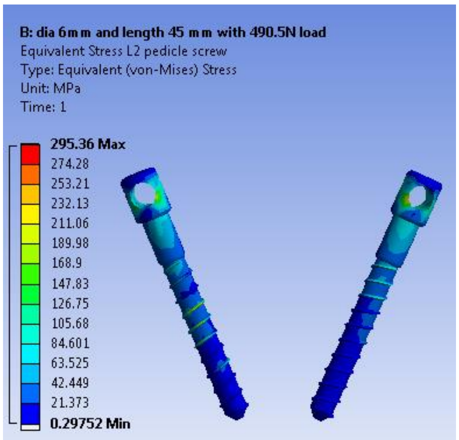
(a)



(b)

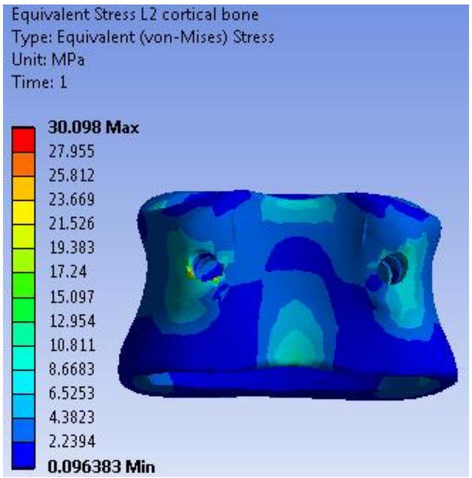


(c)

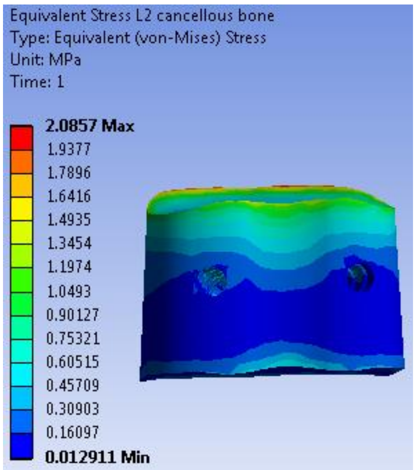


(d)

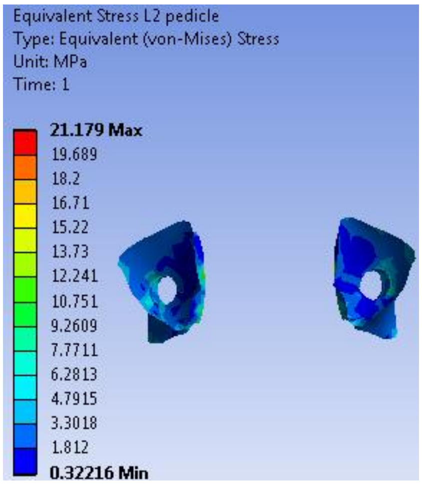
Fig.4.3 Maximum equivalent stress value in screw dia. 6.0mm and length 45 mm under the load value 490 N at (a) cortical bone (b) cancellous bone (c) pedicle (d) pedicle screw



(a)



(b)



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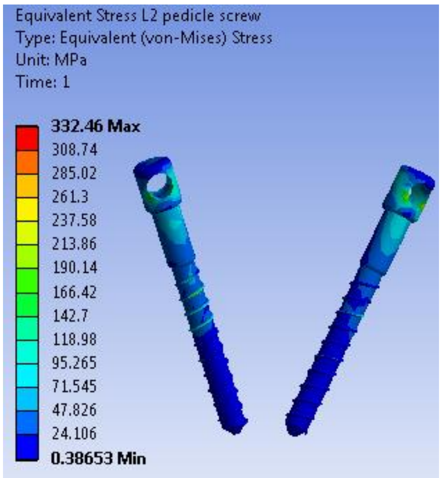
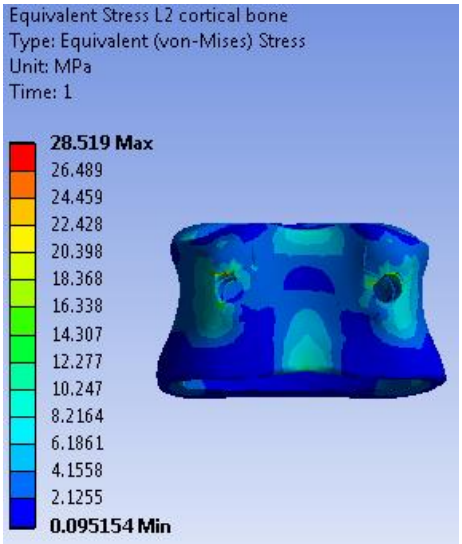
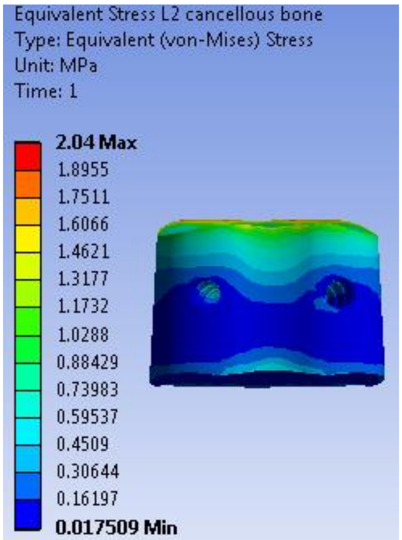


(d)

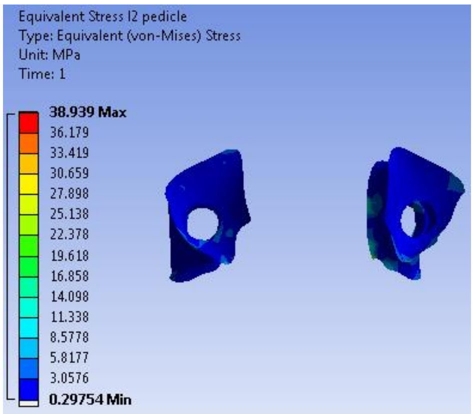
Fig.4.4 Maximum equivalent stress value in screw dia. 6.0mm and length 50 mm under the load value 588.6 N at (a) cortical bone (b) cancellous bone (c) pedicle (d) pedicle screw



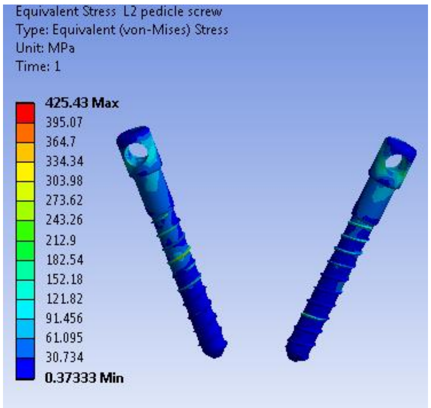
(a)



(b)

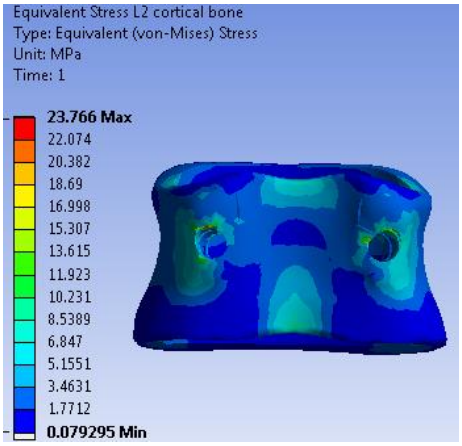


(c)

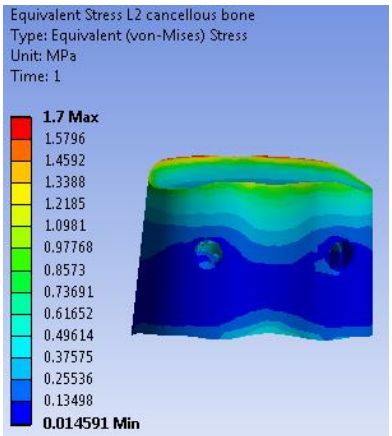


(d)

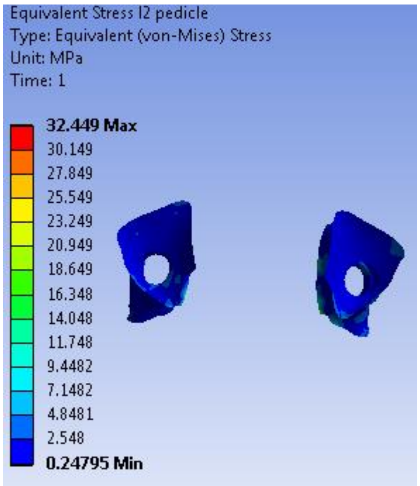
Fig.4.5 Maximum equivalent stress value in screw dia. 6.5mm and length 45mm under the load value 588.6 N at (a) cortical bone (b) cancellous bone (c) pedicle (d) pedicle screw



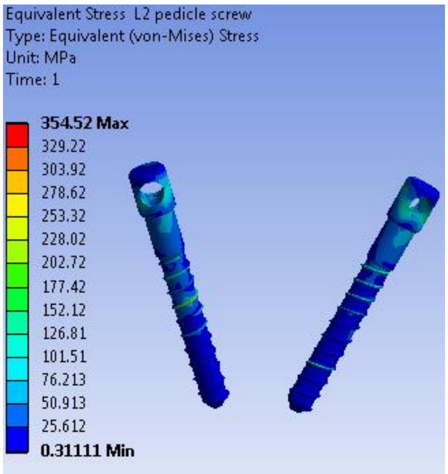
(a)



(b)

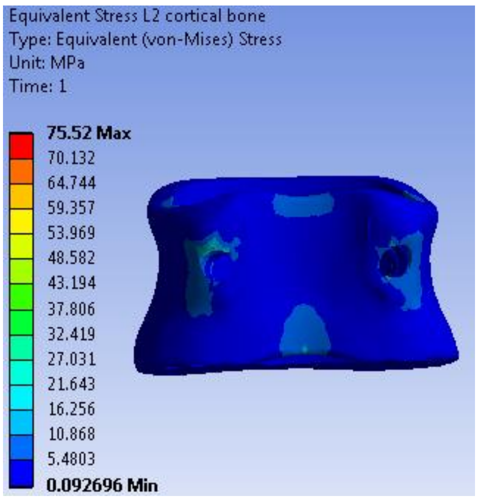


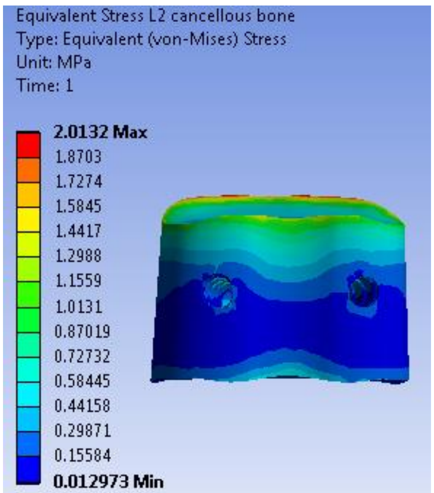
(c)



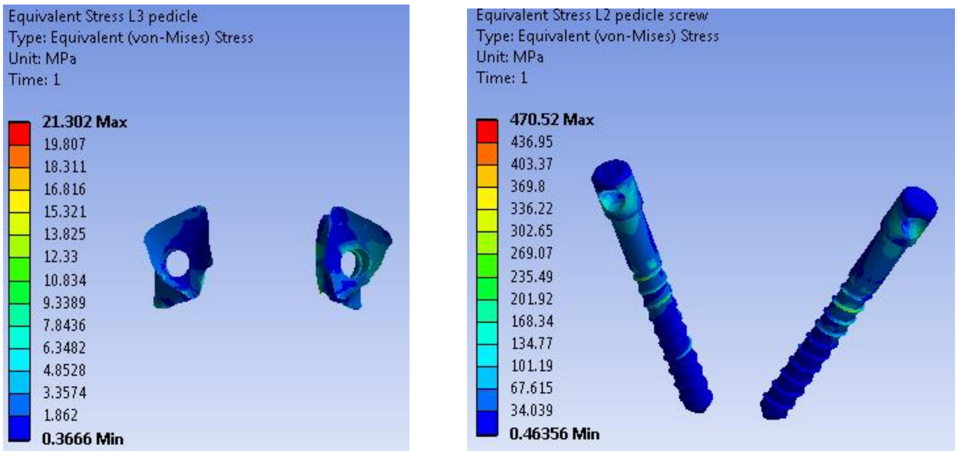
(d)

Fig.4.6Maximum equivalent stress value in screw dia. 6.5mm and length 45mm under the load value 490.5 N at (a) cortical bone (b) cancellous bone (c) pedicle (d) pedicle screw





(a) (b)



(c) (d)

Fig.4.7 Maximum equivalent stress value in screw dia. 6.5mm and length 50mm under the load value 588.6 N at (a) cortical bone (b) cancellous bone (c) pedicle (d) pedicle screw

4.3. Summary

In many regions tetrahedral meshes generated and provide bonded interface conditions. Equivalent (von Mises) stress generated at different portions of lumbar vertebrae like cortical, cancellous, pedicle. Pedicle screw and rod have highest mechanical properties in this implant lumbar vertebrae.

5. Result and analysis

The distributions of maximum equivalent stress in different regions of lumbar vertebrae L2 to L4 with pedicle screw considered with total deformation. After simulation all results are listed in tabular form are shown below. The following tables consists of maximum stress values obtained from ANSYS at pedicle screw, cortical, pedicle and cancellous bone.

Table 5.1. Equivalent stresses and deformation in lumbar vertebrae L2 with implant

S.No	Pedicle screw size(mm)	Load (N)	Maximum Equivalent stresses (MPa)				Total deformation (mm)
	Conditions		Cortical bone	pedicle	Cancellous bone	screw	Pedicle screw
1	Diameter 5.0 and Length 45	588.6	94	46	2	478	1.42
		490.5	78	38	1.67	399	1.18
2	Diameter 5.5 and Length 45	588.6	54	7.3	2.05	227	0.64
		490.5	45	6.0	1.71	189	0.08
3	Diameter 6.0 and Length 45	588.6	41	22	2.04	354	1.56
		490.5	34	19	1.70	295	1.30
	Diameter 6.5 and Length 45	588.6	29	39	2.04	425	1.47
		490.5	24	32	1.70	354	1.23

5	Diameter 5.0 and Length 50	588.6	73	34	2.01	613	1.61
		490.5	61	29	1.67	510	1.34
6	Diameter 5.5 and Length 50	588.6	60	17	2.01	597	1.6
		490.5	50	14	1.67	497	1.33
7	Diameter 6.0 and Length 50	588.6	30	21	2.0	332	1.6
		490.5	25	17	1.73	227	1.39
8	Diameter 6.5 and Length 50	588.6	76	21	2.01	470	1.57
		490.5	62	18	1.67	396	1.30

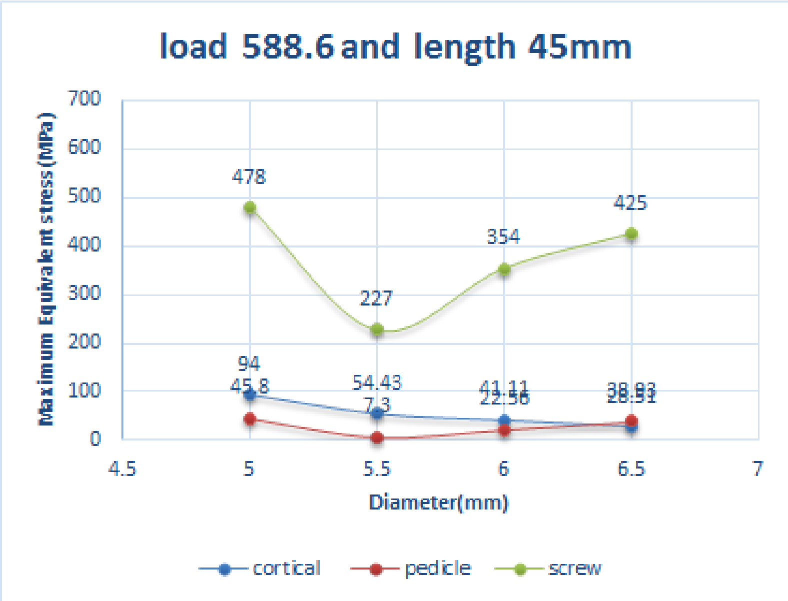
Table 5.2. Equivalent stresses in lumbar vertebrae L4

S.No	**Pedicle screw size(mm)**	**Load (N)**	**Maximum Equivalent stresses(MPa)**				**Total deformation (mm)**
	conditions		**Cortical bone**	**pedicle**	**Cancellous bone**	**screw**	**Pedicle screw**
1	Diameter 5.0 and Length 45	588.6	8.5	10.82	0.67	98.28	0.08
		490.5	7.0	9.0	0.56	81	0.06
2		588.6	7	8.11	0.13	50	0.08

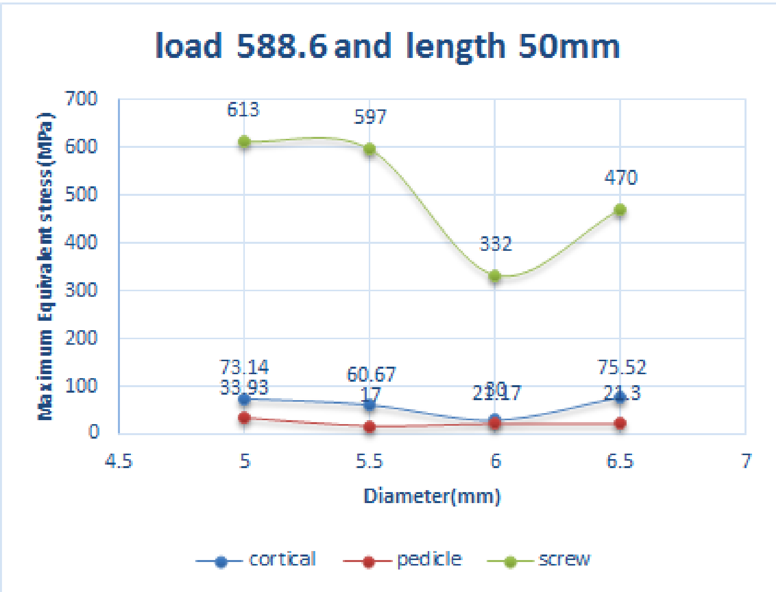
	Diameter 5.5 and Length 45	490.5	6	6.67	0.11	41	0.06
3	Diameter 6.0 and Length 45	588.6	6.2	6.11	0.70	2	0.04
		490.5	5.19	5.0	0.50	68	0.03
4	Diameter 6.5 and Length 45	588.6	11	10	0.73	39	0.06
		490.5	9.5	8.28	0.61	33	0.05
5	Diameter 5.0 and Length 50	588.6	9.0	10.37	0.70	133	0.07
		490.5	7.40	8.64	0.58	111	0.06
6	Diameter 5.5 and Length 50	588.6	9.22	9.91	0.75	50	0.06
		490.5	7.6	8.2	0.62	42	0.05
7	Diameter 6.0 and Length 50	588.6	8.0	9.19	0.69	38	0.05
		490.5	6.7	7.6	0.57	32	0.04
8	Diameter 6.5 and Length 50	588.6	8.34	9.21	0.67	47	0.05
		490.5	6.93	7.69	0.56	39	0.04

Table 5.1 shows that stress developed at any regions of 3D lumbar vertebrae L2 portion have highest value as compare to lower vertebrae L4 as shown in table 5.2. So upper lumbar vertebrae L2 has be taken for further process.

We have plotted graphs between maximum equivalent stress versus diameter under various load conditions and length of pedicle screw for L2 vertebrae because it has highest output value for simulation. Further statistical analysis was done to optimize the pedicle screw dimension for lumbar vertebrae regions using output value of simulation. (Fig. 5.1 a) depicts a relationship between Maximum equivalent stress (Mpa) v/s diameter (mm) at a load value of 588.6N and length 45mm. & (Fig. 5.1 b) depicts a relationship between Maximum equivalent stress (Mpa) v/s diameter (mm) at a load value of 588.6N and length 50mm.



(a)

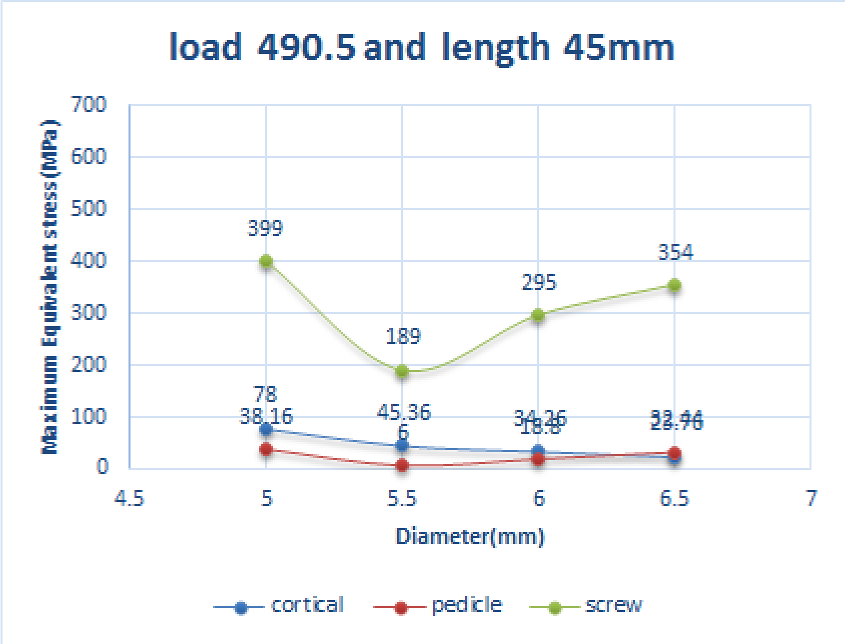


(b)

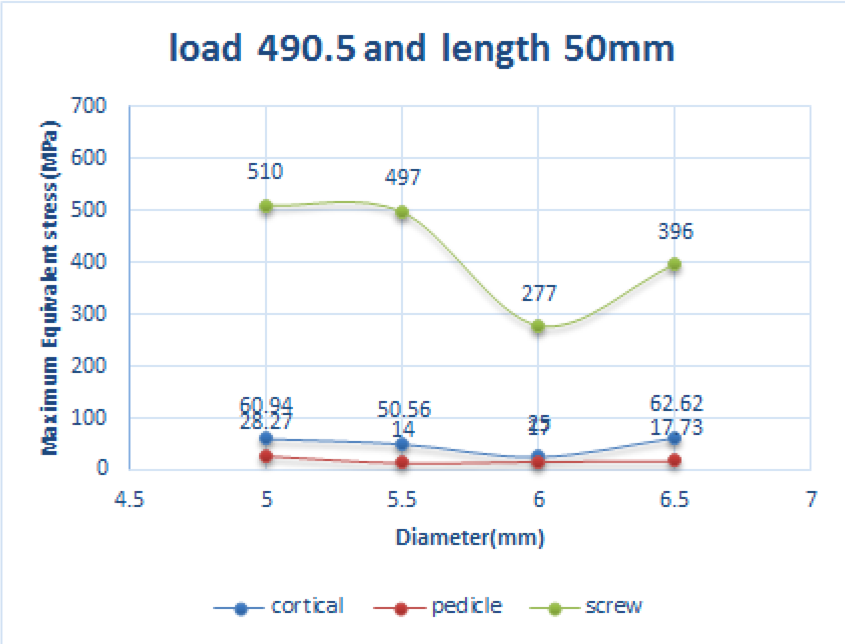
Fig.5.1 Maximum equivalent stress (Mpa) v/s diameter (mm) at (a) load value of 588.6N and length 45mm and (b) load value of 588.6N and length 50mm

(Fig. 5.2 a) depicts a relationship between Maximum equivalent stress (Mpa) v/s diameter (mm) at a load value of 490.5N and length 45mm. & (Fig. 5.2 b) depicts a relationship between

Maximum equivalent stress (Mpa) v/s diameter (mm) at a load value of 490.5N and length 50mm.



(a)



(b)

Fig.5.2 Maximum equivalent stress (Mpa) v/s diameter (mm) at (a) load value of 490.5N and length 45mm and (b) load value of 490.5N and length 50mm

In this fig.5.1 (a) & (b) and fig. 5.2 (a) & (b) maximum equivalent stresses developed lumbar vertebrae region is cortical bone and in implant is pedicle screw. The vertebral body contains of an external shell of great strength cortical bone reinforced within by the cancellous bone. Cancellous bone has minimal stress as compare to cortical bone. From the above table (5.1)

& table (5.2) results it is clear that the main region of stress generation is cortical region, which is our point of concern from the results.

5.1. Statistical Analysis

It is very convenient tool to acquire imprecise answers when the authentic process is very complex or unidentified in its true form. It provide optimal set of input parameters also to identify the effect of each towards a particular output. Taguchi methodology emphasizes over the choice of the foremost best answer over the set of specified inputs (i.e. diameter, length and load) with a reduced price and magnified quality. Thus, the fashionable day approach to seek out the best output over a group of given input are often simply dole out by the employment of Taguchi methodology instead of exploitation the other typical ways. This methodology contains an extensive scope of use varied from the engineering field to medical field .During this chapter taguchi methodology is employed for experiment

5.1.2Taguchi method

Taguchi technique could be a controlling instrument for identification of outcomes of varied method parameters supported orthogonal array (OA) experiments that delivers abundant reduced variance for the experiments with an optimum setting of method management parameter. Taguchi recommends the employment of loss perform to live the deviation between the experimental worth and therefore the desired worth that is more reworked into S/N (S/N). During this work L8 orthogonal array mixed (table.5.1) was accustomed do the experiments and therefore the experimental result were analysed mistreatment Taguchi technique. so as to measure the variability of the outcomes among a pre-defined vary, signal to noise magnitude relation (S/N ratio) analysis was through with most equivalent stress in plant tissue bone, pedicle, and pedicle screw because the output. For decrease of stress the S/N magnitude relation was calculated using smaller is best criterion. In S/N magnitude relation graph choose worth shows that best condition.

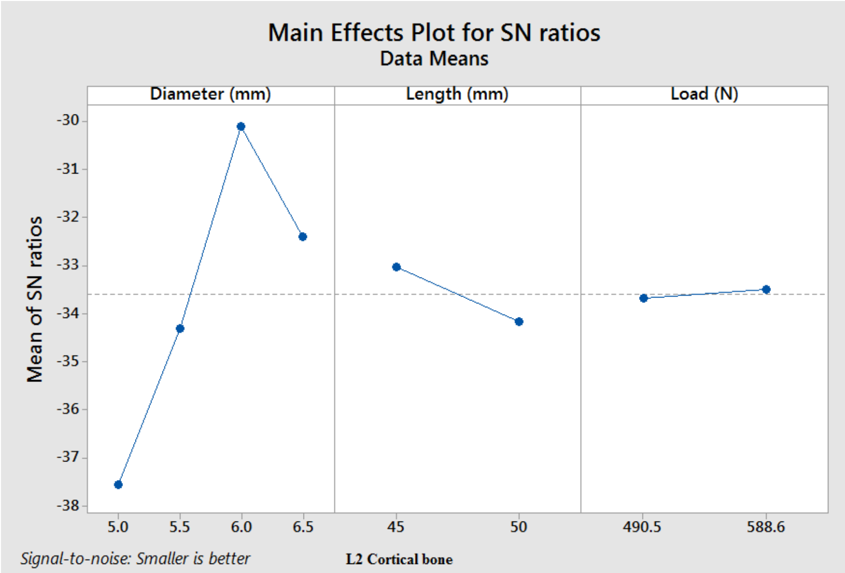
Since the investigational design is orthogonal, it was probable to distinct out the conclusion of each parameter at changed levels. Graph plotted between input parameter (diameter, length, and load) and output using table5.4.

Table 5.3 L8 orthogonal array matrix

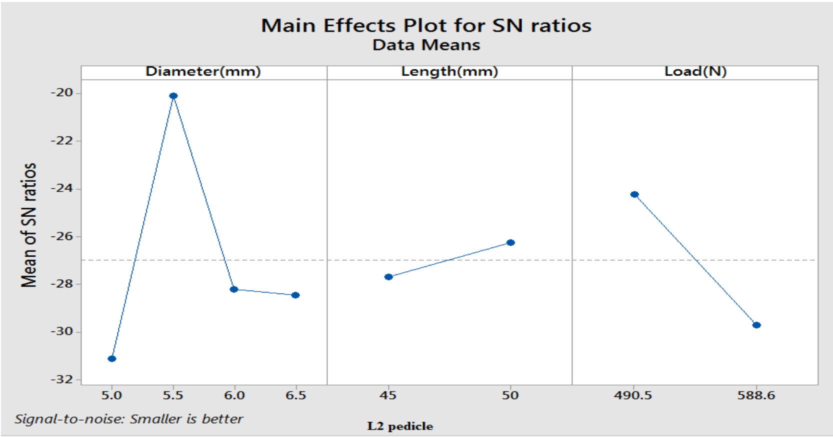
Parameter	Code	Level							
Diameter	A	1	1	2	2	3	3	4	4
Length	B	1	2	1	2	1	2	1	2
Load	C	1	2	1	2	2	1	2	1

Table 5.4. Experimental results

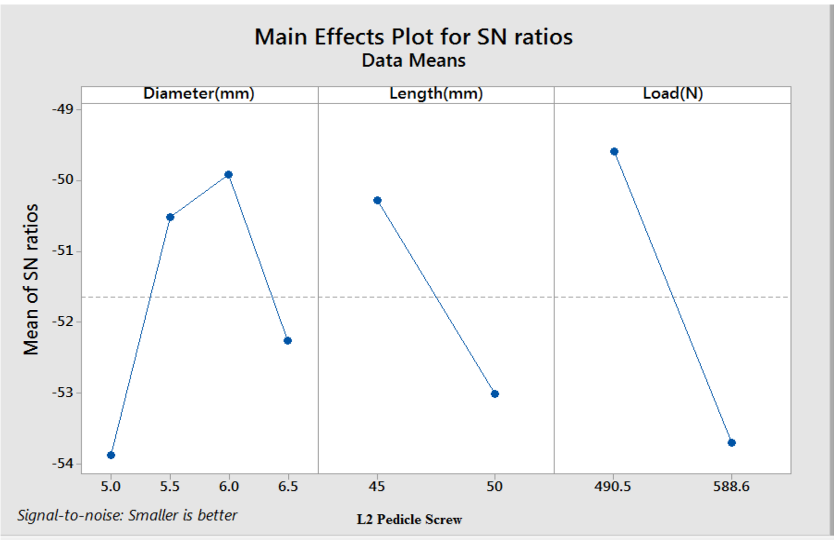
S.No	**Input parameter**			**Output**		
				Maximum Equivalent stress		
	Diameter(mm) A	**Length(mm) B**	**Load (N) C**	**Cortical bone (MPa)**	**Pedicle (MPa)**	**Pedicle screw (MPa)**
1	5.0	45	490.5	78	38	399
2	5.0	50	588.6	73	34	613
3	5.5	45	490.5	45	6	189
4	5.5	50	588.6	60	17	597
5	6.0	45	588.6	41	23	354
6	6.0	50	490.5	25	17	277
7	6.5	45	588.6	28	39	425
8	6.5	50	490.5	62	18	396



(a)



(b)



(c)

Fig.5.3 (a) main effect plot for SN ratios of cortical bone, (b) main effect plot for SN ratios of pedicle, (c) main effect plot for SN ratios of pedicle screw.

According to the main effect plot of SN ratios fig. (a) it is clear that for cortical region the suitable values for screw diameter, length and load values is 6mm, 45mm and 588.6 N respectively.in fig. (b) for pedicle region the suitable values for screw diameter, length and load values is 5.5mm, 50mm and 490N respectively, for pedicle screw the suitable values for screw diameter, length and load values is 6mm, 50mm and 490.5 N respectively

CHAPTER 6

6. Conclusions and future work

6.1. Conclusions

Some vital biomechanical choices are often drawn from these outcomes. First, most equivalent stress within the numerous regions of the body part vertebrae (cortical bone, cancellous bone, and pedicle) is affetced by the various size of pedicel screw. Second, from a biomechanical viewpoint, screw size given in table (5.1) like diameter surpassing from 5.0 mm to 6.0 mm and length increasing 45mm to 50mm beneath the compressive load to 490.5 N is perfect for internal fixation of body part vertebrae L2. Our results are restricted by assumptions regarding the properties of materials and by the basic models employed in finite component analysis. These results should be thought of, then, as an earliest guide to choosing screws, since approaching clinical studies are needed to substantiate the results

6.2. Future scope

In upcoming some adaptations could make the suggested analysis smarter. The adaptations foreseen may be the following:

- Use multi optimization tools for selection of pedicle screw size.
- Modified screw thread design to reduce the stresses and also increase stability.
- Use number of 3D modal of lumbar spine to confirmation of proposed dimension of pedicle screw.

References

1. Qi, W., Yan, Y. B., Zhang, Y., Lei, W., Wang, P. J., & Hou, J. (2011). Study of stress distribution in pedicle screws along a continuum of diameters: a three-dimensional finite element analysis. Orthopaedic surgery, 3(1), 57-63.
2. Mohamad Shahrul Effendy, K. (2010). Finite Element of Human Spine CAD Model Analysis.
3. Kim, B. S. (2011). A follower load as a muscle control mechanism to stabilize the lumbar spine.
4. Buckenmeyer, L. E. (2013). Optimization of pedicle screw depth in the lumbar spine: biomechanical characterization of screw stability and pullout strength.
5. Biswas, J., Karmakar, S., Majumder, S., Chowdhury, A., 2012, A finite element study of spinal implant (pedicle screw) design for lumbar (l3–l5) vertebra, Indian Journal of Biomechanics, 3(1-2), 50-60.
6. Rasoulinejad, P. (2013). Design and Development of a Novel Expanding Pedicle Screw for Use in the Osteoporotic Lumbar Spine.
7. Van de Kelft, E., Costa, F., Van der Planken, D., & Schils, F. (2012). A prospective multicenter registry on the accuracy of pedicle screw placement in the thoracic, lumbar, and sacral levels with the use of the O-arm imaging system and StealthStation Navigation. Spine, 37(25), E1580-E1587.
8. Silbermann, J., Riese, F., Allam, Y., Reichert, T., Koeppert, H., & Gutberlet, M. (2011). Computer tomography assessment of pedicle screw placement in lumbar and sacral spine: comparison between free-hand and O-arm based navigation techniques. European Spine Journal, 20(6), 875-881.
9. Allam, Y., Silbermann, J., Riese, F., & Greiner-Perth, R. (2013). Computer tomography assessment of pedicle screw placement in thoracic spine: comparison between free hand and a generic 3D-based navigation techniques. European Spine Journal, 22(3), 648-653.
10. Sugimoto, Y., Ito, Y., Tomioka, M., Shimokawa, T., Shiozaki, Y., Mazaki, T., & Tanaka, M. (2010). Upper lumbar pedicle screw insertion using three-dimensional fluoroscopy navigation: assessment of clinical accuracy. Acta Med Okayama, 64(5), 293-297.
11. Bijukachhe, B., Shrestha, B. K., Pandey, J. R., & Banskota, A. K. (2013). Free hand insertion of pedicle screws in Dorsal/Lumbar/Sacral spine–Our experience. Nepal Orthopaedic Association Journal, 2(1), 35-42.

12. Salo, S., Leinonen, V., Rikkonen, T., Vainio, P., Marttila, J., Honkanen, R., & Sirola, J. (2014). Association between bone mineral density and lumbar disc degeneration. Maturitas, 79(4), 449-455.
13. Douchi, T., Kuwahata, R., Matsuo, T., Kuwahata, T., Oki, T., Nakae, M., & Nagata, Y. (2004). Age-related change in the strength of correlation of lumbar spine bone mineral density with other regions. Maturitas, 47(1), 55-59.
14. Sabo, M. T., Pollmann, S. I., Gurr, K. R., Bailey, C. S., & Holdsworth, D. W. (2009). Use of co-registered high-resolution computed tomography scans before and after screw insertion as a novel technique for bone mineral density determination along screw trajectory. Bone, 44(6), 1163-1168.
15. Singel, T. C., Patel, M. M., & Gohil, D. V. (2004). A study of width and height of lumbar pedicles in Saurashtra region. J Anat Soc India, 53(1), 4-9.
16. Gocmen-Mas, N., Karabekir, H., Ertekin, T., Edizer, M., Canan, Y., & Duyar, I. (2010). Evaluation of lumbar vertebral body and disc: a stereological morphometric study. Int J Morphol, 28(3), 841-847.
17. Zhou, S. H., McCarthy, I. D., McGregor, A. H., Coombs, R. R. H., & Hughes, S. P. F. (2000). Geometrical dimensions of the lower lumbar vertebrae–analysis of data from digitised CT images. European Spine Journal, 9(3), 242-248.
18. Ben-Hatira, F., Saidane, K., & Mrabet, A. (2012). A finite element modeling of the human lumbar unit including the spinal cord.
19. Li, H. (2011). An Approach to Lumbar Vertebra Biomechanical Analysis Using the Finite Element Modeling Based on CT Images. INTECH Open Access Publisher.
20. Divya, V., & Anburajan, M., 2011, Finite element analysis of human lumbar spine. In Electronics Computer Technology (ICECT), 2011 3rd International Conference on (Vol. 3, pp. 350-354). IEEE.
21. Zulkifli, A., Ariffin, A. K., & Rahman, M. M. (2011). Probabilistic Finite Element Analysis of Vertebrae of the Lumbar Spine under hyperextension loading. International Journal of Automotive and Mechanical Engineering, 3(1), 256-264.
22. Karabekir, H. S., Gocmen-mas, N., Edizer, M., Ertekin, T., Yazici, C., & Atamturk, D. (2011). Annals of Anatomy Lumbar vertebra morphometry and stereological assesment of intervertebral space volumetry : A methodological study, 193, 231–236.
23. Shea, T. M., Laun, J., Gonzalez-Blohm, S. A., Doulgeris, J. J., Lee, W. E., Aghayev, K., & Vrionis, F. D. (2014). Designs and techniques that improve the pullout strength of

pedicle screws in osteoporotic vertebrae: current status. BioMed research international, 2014.

24. Kurutz, M., & Oroszváry, L. (2012). Finite Element Modeling and Simulation of Healthy and Degenerated Human Lumbar Spine. INTECH Open Access Publisher.
25. Deoghare, A. B., Kashyap, S., & Padole, P. M. (2013). Investigation of biomechanical behavior of lumbar vertebral segments with dynamic stabilization device using finite element approach. 3D Research, 4(1), 1-6.
26. Schmidt, H., Heuer, F., & Wilke, H. J. (2009). Which axial and bending stiffnesses of posterior implants are required to design a flexible lumbar stabilization system? Journal of biomechanics, 42(1), 48-54.
27. Rohlmann, A., Burra, N. K., Zander, T., & Bergmann, G. (2007). Comparison of the effects of bilateral posterior dynamic and rigid fixation devices on the loads in the lumbar spine: a finite element analysis. European Spine Journal, 16(8), 1223-1231.
28. Kurutz, M. (2010). Finite element modelling of human lumbar spine. INTECH Open Access Publisher.
29. Chen, S. I., Lin, R. M., & Chang, C. H. (2003). Biomechanical investigation of pedicle screw–vertebrae complex: a finite element approach using bonded and contact interface conditions. Medical engineering & physics, 25(4), 275-282.
30. Rohlmann, A., Bergmann, G., & Graichen, F. (1997). Loads on an internal spinal fixation device during walking. Journal of biomechanics, 30(1), 41-47.